National Aeronautics and Space Administration

Human Spaceflight Architecture Team (HAT) Technology Planning

NAC Briefing
3/6/12

Chris Culbert/Scott Vangen
Human Space Flight Architecture Team

Agenda

HAT Overview

- HAT History, Cycles, and CDF
- Architecture, Destination, Element Analysis
- ISECG & GER

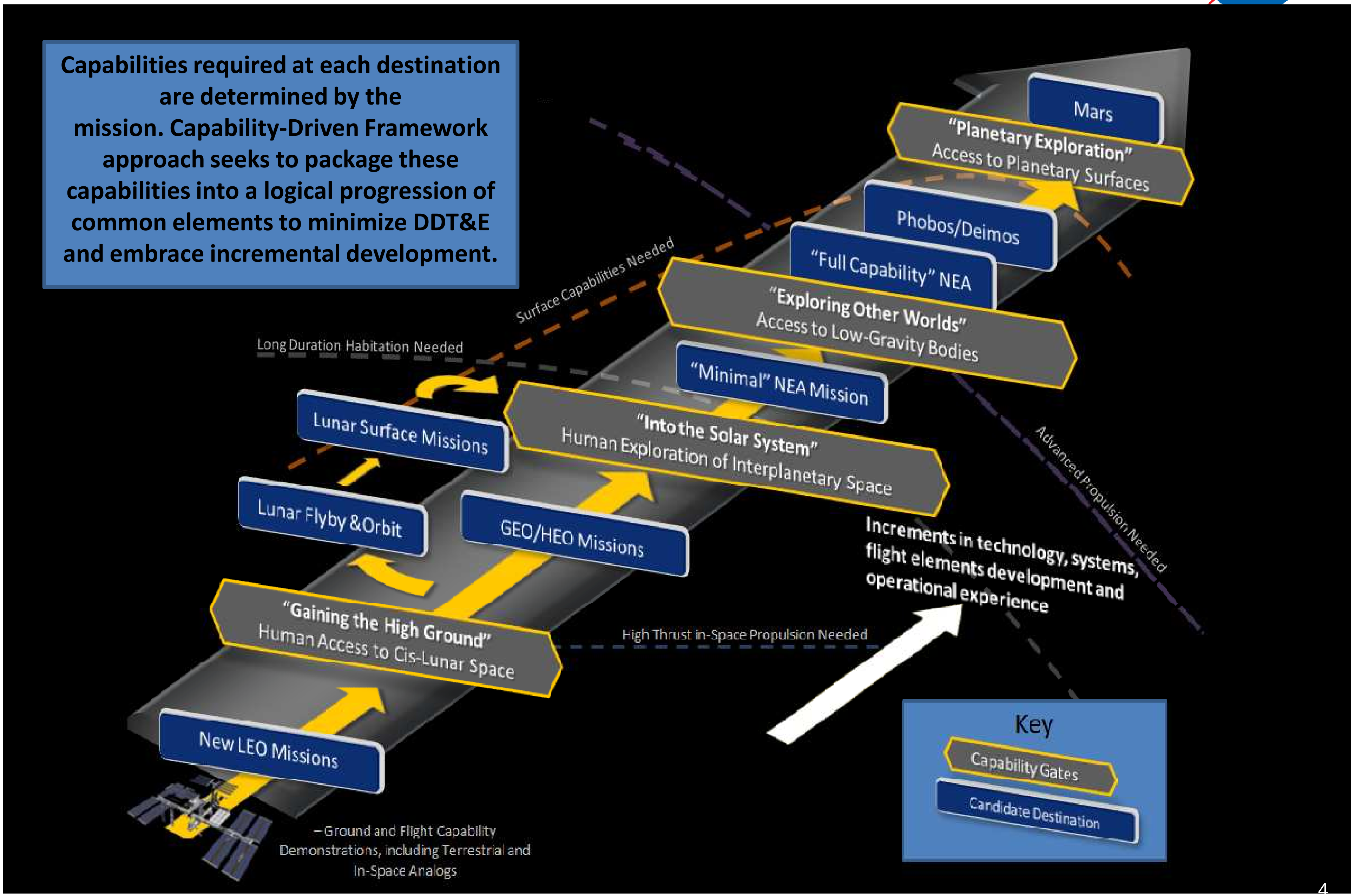
HAT Technology Development

- Process & Products
- HAT Cycle 2011-C “Quick-Look” Summary
- ISECG Technology Assessment Team (TAT)
- AES Technology Mapping Assessment

NASA's Human Spaceflight Architecture Team (HAT)

- **On-going, cross-Agency, multi-disciplinary, study team that conducts strategic analysis cycles to assess integrated development approaches for architectures, systems, mission scenarios, and Conops for human and related robotic space exploration.**
  - During each analysis cycle, HAT iterates and refines design reference mission (DRM) definitions to inform integrated, capability-driven approaches for systems planning within a multi-destination framework.
- **Key Activities in 2011**
  - Prepared DRMs that frame key driving level 1 requirements for SLS & Orion MPCV
  - Developed technical content & mission definitions for discussion with the international community developing the Global Exploration Roadmap
  - Advanced Capability Driven Framework (CDF) concept including more extended reviews of both capabilities needed and development options.
  - Provided technical links between CDF and level 1 requirements for SLS/MPCV
  - Developed performance data for key decisions on SLS initial capability and upper stage options

Capability Driven Exploration

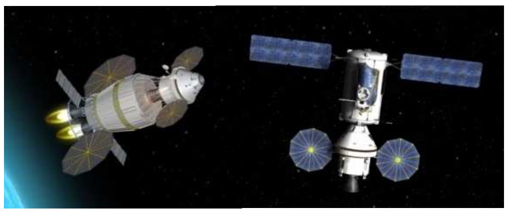


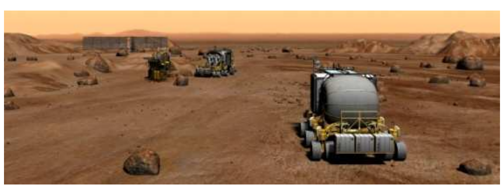
Key Findings from Multiple Cycles

- **It's important to look at multiple DRMs to understand which cases drive requirements**
- **SLS Performance**
  - 105t to LEO captures majority of DRMs; HAT input to Level 1 requirements
  - Payload volume remains a challenge for more complex missions
- **Developed a consistent set of ground rules, assumptions and margins across DRMs that must be regularly coordinated with the programs**
- **Activities at the destination need as much attention as the transportation components**
- **A focused technology investment program is needed to enable future missions; integration & dialogue with AES & OCT is critical to ensure priorities**

Primary Transportation DRMs

Select destinations used to drive transportation systems requirements and assess impacts of changes in mission assumptions





Proposed Status	ISECG	DRM ID	DRM Title	Dest.
Cycle-C	N	LEO_UTL_2A	LEO Utilization - Non-ISS	LEO
Cycle-C	Y	CIS_LP1_1A	Lunar Vicinity - EM L-1	E-M L1
Cycle-C	Y	CIS_LP1_1B	Lunar Vicinity - EM L-1 DSH Delivery	E-M L1
Cycle-C	Y	CIS_LP1_1C	Lunar Vicinity - EM L-1 with Pre-deployed DSH	E-M L1
Cycle-C	Y	CIS_LLO_1A	Low Lunar Orbit	LLO
Cycle-C	Y	LUN_SOR_1A	Lunar Surface Polar Access - LOR/LOR	Moon
Cycle-C	Y	LUN_CRG_1A	Lunar Surface Cargo Mission	Moon
Cycle-C	N	NEA_MIN_1A	Minimum Capability, Low Energy NEA	NEA
Cycle-C	Y	NEA_MIN_1B	Minimum Capability, Low Energy NEA with Pre-deployed DSH	NEA
Cycle-C	N	NEA_MIN_2A	Minimum Capability, High Energy NEA	NEA
Cycle-C	N	NEA_FUL_1A	Full Capability, High Energy NEA with SEP	NEA
Cycle-C	Y	NEA_FUL_1B	Full Capability, High Energy NEA with SEP and pre-deployed DSH	NEA
Forward Work	N	MAR_PHD_1A	Martian Moon: Phobos/Deimos	Mars Moon
Forward Work	N	MAR_SFC_1A	Mars Landing	Mars Surface

Full Capability, High Energy NEA (2008EV5) with SEP

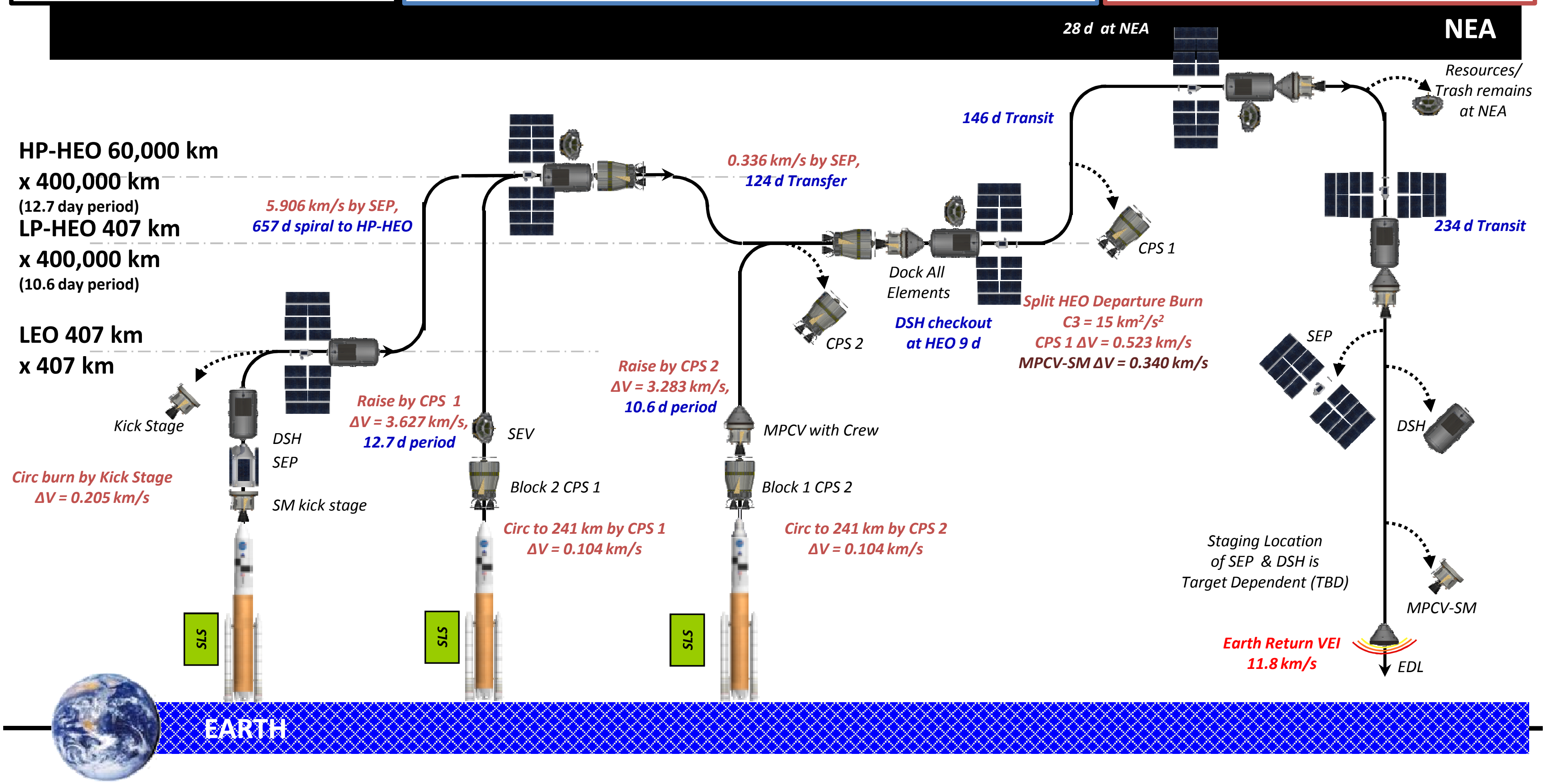
NEA_FUL_1A_C11C1 - Hybrid with HP HEO Aggregation and LP HEO Crew Rendezvous

Transportation:
- 2008EV5: Opportunity in 2024
- Crewed Mission Duration ~428 days
- Block 1 CPS (no LBO), Block 2 CPS (LBO)
- Entry Velocity exceeds MPCV capability (11.5 km/s)

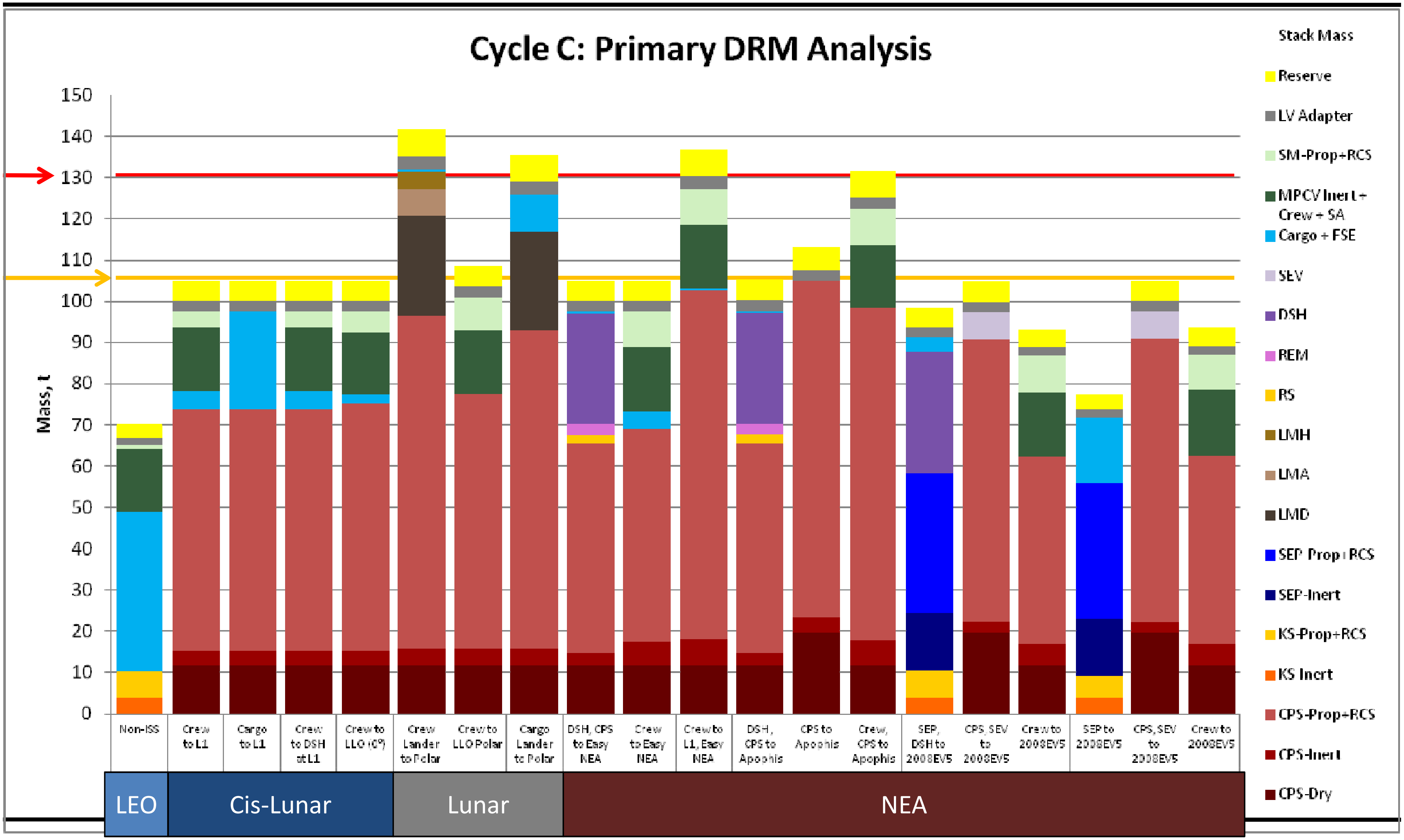
Destination:
- Time at Destination: 28 d
- Cargo & FSE Mass: 500 kg
  - Type: TBD
- Resources/Trash left: 11.36 t
  - Type: 2 t Trash, SEV, Cargo & FSE
- Samples/Cargo at NEA Departure: 250 kg
- Samples/Cargo returned to Earth: 100 kg
  - Type: TBD

Sensitivities:
- 2^{nd} SEV, 1000 kg cargo + FSE
- 56 d at NEA, 2^{nd} SEV, 1000 kg cargo + FSE

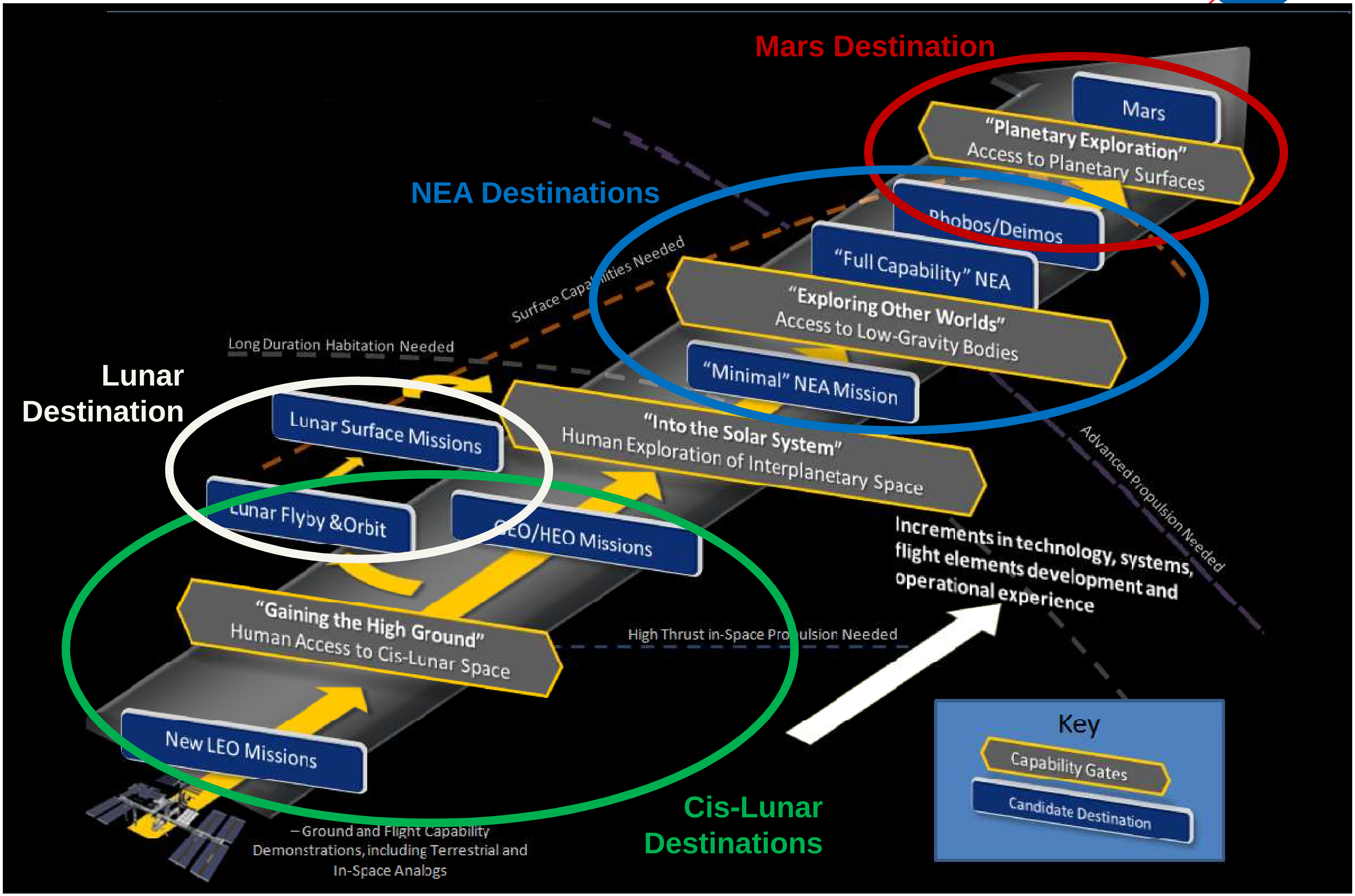
Chart Notes:
- spacecraft icons are not to scale
- ΔV's include 5% FPR (not applied to MPCV burns)
- RCS burns not displayed in chart
- Not all discrete burns displayed
- SEP transit includes 95% thrusting duty cycle



DRM Comparison

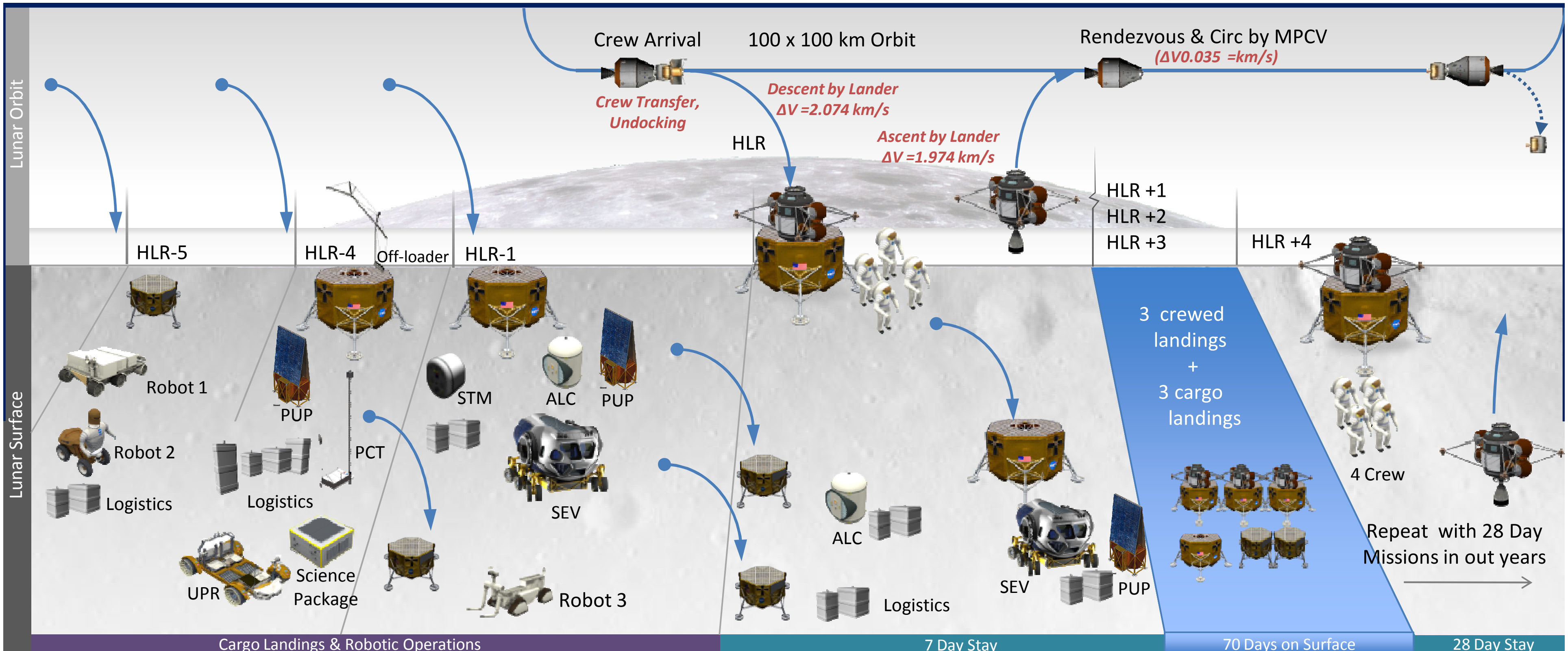


Capability Driven Roadmap – Destinations



GER Extended Stay & Surface Mobility Emphasis

4 large cargo landers, 6 small cargo landers, 5 crewed missions



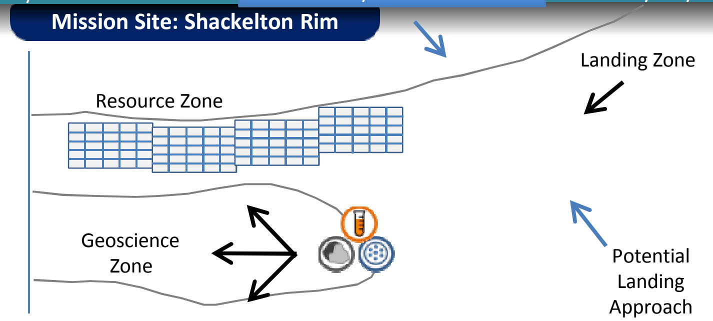
Mission Summary

Five years prior to Human Lunar Return, cargo missions begin to deliver robotics and science equipment. The crew arrives with two large cargo landers and two small logistics landers, and spends 7 days on the surface. Over the next five years, a total of five crewed missions with surface stays of up to 28 days are completed.

Select Elements

Element	QTY		Element	QTY
Centaur 2	1		ALC	7
Rapier	1		STM	1
PUP	3		SEV	2
PCT	1		Selene	1

Mission Site: Shackelton Rim

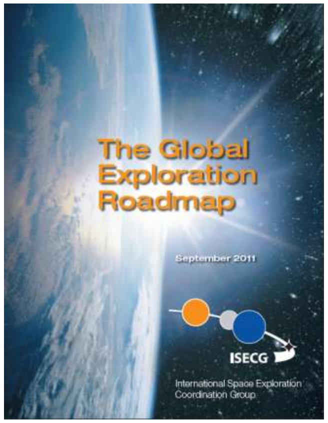


Elements Required By Destination

Phase	Required Element	Capability	For Destinations				
			L1/L2	Lunar Surface	Asteroid	Mars Orbit	Mars Surface
Getting There	**Space Launch System (SLS)**	Launch	**X**	**X**	**X**	X	X
	Cryo Propulsion Stage (CPS)	High Thrust/Near Earth	**X**	**X**	**X**	Option	Option
	Solar Electric Propulsion (SEP)	Low Thrust/Near Earth			Option	Option	Option
	Nuclear Thermal Propulsion (NTP)	High Thrust/Beyond LEO			Option	Option	Option
	Nuclear Electric Propulsion (NEP)	Low Thrust/Beyond LEO			Option	Option	Option
	Depot	In-Space Logistics	Option	Option		Option	Option
	Deep Space Habitat (DSH)	In-Space Habitation	**X**		**X**	**X**	**X**
	Landers	Descent		**X**			**X**
Working There	**Surface Hab**	Surface Habitation		**X**			**X**
	Multi-Mission Space Exploration Vehicle (MMSEV)	Micro-g Sortie			**X**	**X**	
	Cargo Hauler	Cargo Mobility	Option	Option	Option	Option	Option
	Robotics and EVA Module (REM)	Logistics/Resupply	Option		Option	Option	
	In-Situ Resource Utilization (ISRU)	In Situ Resource Utilization		**X**			**X**
	Fission Surface Power System	Surface Power		Option			**X**
	Surface Rover	Surface Mobility		**X**			**X**
	EVA Suits	EVA (nominal)	**X**	**X**	**X**	**X**	**X**
Coming Home	**Ascent Vehicle**	Ascent		**X**			**X**
	Orion	Crew Return	**X**	**X**	**X**	**X**	**X**

ISECG (Int'l Space Exploration Coordination Group) Global Exploration Roadmap (GER)

- **The first iteration of the GER was released Sept 2011**
- **GER enhances international coordination and cooperation in human exploration by enabling discussion of these key areas**
  - Goals and objectives
  - Technically feasible/programmatically implementable mission scenarios: Asteroid Next and Moon Next
  - Near-Term opportunities for coordination and cooperation



- **GER is non-binding but reflects international consensus consistent with existing policies of 12 participating agencies, informs individual agency decisions**
- **Next iteration planned for Sept 2012. Will reflect any available updates resulting from several key activities:**
  - Planned community engagement, including NASA GER Workshop and IAF/AIAA Global Space Exploration Conference
  - ISS Program IEWG activities
  - ISECG work on knowledge gaps for each destination, technology needs mapped to scenarios and potential gaps, early DRMs
- **The NASA technical contributions to GER scenarios are developed by the HAT team**

Forward Work Issues and Concerns

- **In Space Propulsion**
  - Wide variety of options for how to provide in-space burns:
    - Cryo Propulsion Stage, new stage developed for long life in-space
    - Initial Cryo Propulsion Stage; off the shelf capability, limited life in space
    - Low thrust options for cargo like Solar Electric Propulsion
  - Trade space of mission capture, affordability, and partnerships is likely to be very complex
- **Technology & Capability priorities**
  - What are the best ways to utilize the agencies limited technology funding to enable a wide variety of future human spaceflight capabilities?
  - Early emphasis on ECLSS reliability and cryo technologies looks relevant to almost all destinations
- **Earth Moon Lagrange Point 2 Mission**
  - How does an L2 waypoint enable missions to other destinations?
  - Reviewing multiple approaches for how to take best advantage of capabilities deployed in cis-lunar space to prepare for missions to other destinations
- **Mars Mission**
  - How should eventual Mars mission influence earlier missions and investments?
  - Build Mars Design Reference Architecture 6.0; likely to take into FY13
  - Look at manned missions to Martian moons and how those can reduce mission risk and prepare for eventual human missions to Mars surface

HAT Technology Development Assessment: Process & Products

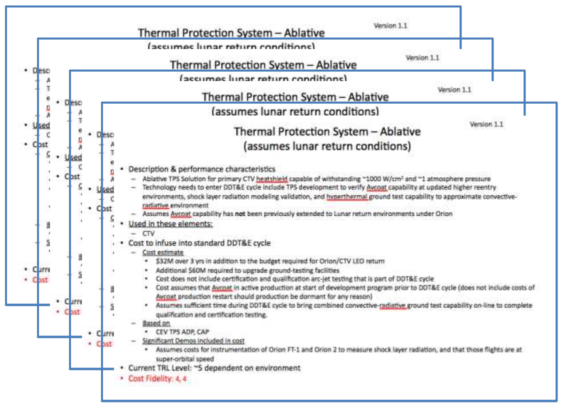
- **Role in influencing human spaceflight technology dialogues & decisions**
  - Provides a CDF architecture driven assessment of technology development requirements ("technology pull") of the transportation & destination elements/capabilities across the spectrum of review cycle DRM's
  - Interfacing, integrating, and vetting inputs across the various stakeholders
    - Engineering & Systems disciplines
    - Technology developers (ETDD/OCT, HRP)
    - HAT Element & Destination Leads
  - Providing a common reference set of products cross-linking data of interest
    - Technology Development 'One-Pagers' for each technology entry
      - Description & Performance Characteristics *(why & what required)*
      - Cost and time estimates, Current TRL level *(how much & when required)*
    - Summary matrix of mapping to element & destination needs (e.g. "green-wall")
    - Note: All technologies mapped to OCT Technology Areas (TA's)
- **Product Benefactors *(activities & communities influenced)***
  - Technology developers for prioritization (e.g. OCT roadmaps)
  - Technology prioritization inputs into AES review/selection process
  - Technology demonstration candidate inputs into MCB Action #5 (ISS Utilization)
  - NASA technology inputs for Global Exploration Roadmap (GER) for ISECG Technology Assessment Team (TAT)
  - National Research Council (inputs into the OCT roadmap review)
  - Analog testbeds planning

Technology Development Assessment:
Technology Development Data Capture Process

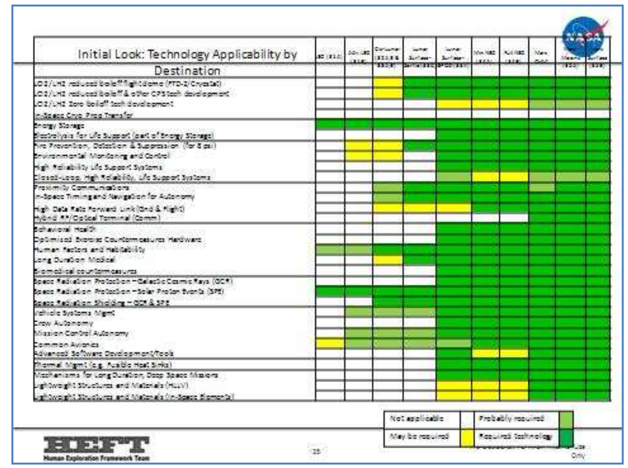
Strategy & DRMs

Element Data

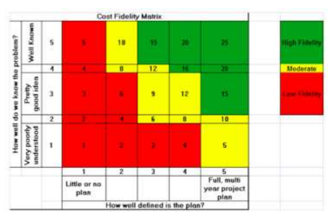
Tech Dev 'One-Pager' Sheets



'Tech Dev' Summary Spreadsheet
(per Strategy/DRM)



Cost Fidelity



Subject Matter Expert POCs
(e.g. OCT, HRP,
Element Leads, SE, etc.)

- Tech Dev Data for HAT Cost Team:
  - Cost, Schedule, Phasing
  - Applicable Elements (per DRM)
- OCT/HRP Data Inputs
- HEDS Data Inputs (e.g. AES priorities, Analogs, ISS demo candidates, etc.)
- ISECG Technology Dev Inputs

Regenerative Fuel Cells

Power Systems (OCT TA-3.1)

EXAMPLE

Version 1.0
10/24/2011

Description

- Long duration energy storage is required for extended surface missions to store solar energy and provide power during low insolation. Applicable to Lunar or Mars surface applications requiring high power and/or long sortie durations.
- RFC system includes a fuel cell and an electrolyzer, each of which can be used independently for power/water generation and H2/O2 generation, respectively. Electrical power can be used for any vehicle. Water and O2 can be used for life support for crewed vehicles. Also applicable to ISRU.
- Technology development includes reducing the number of ancillary components to increase reliability and operational lifetime, and reduce parasitic power losses, mass, and volume.

Performance characteristics

- Power generation >10 kWe for 8 hours or more
- Operable with reactants at >2000 psi to reduce tank volume
- Round trip energy conversion efficiency > 50%
- Minimize mass (TBD Wh/kg)
- Operational life >10,000 hours

Applicable to these Capabilities/Elements; Destinations/Con-Ops

- Driving: Surface Elements, CPS (fuel cell tech advancement, sub-set of regen fuel cell) ; Lunar Surface
- Beneficiary: MPCV (TBR), DSH, Lander ; NEAs

Current TRL Level: 2-3 (regenerative fuel cell), 4 (primary fuel cell), 2 (electrolyzer)

ISS Technology Demonstration:

- Candidate – Proposal submitted for ISS demonstration. Selected for inclusion in Cycle “C”. Not strictly required for technology maturation, but highly beneficial to ensure system operation in microgravity.
- Technology would provide operational enhancement capability by providing a small amount of electrical power or clean water and oxygen.

Regenerative Fuel Cells
Power Systems (OCT TA-3.1)

EXAMPLE

Version 1.0
10/24/2011

- **Cost to infuse into standard DDT&E cycle: $xM**
  - Fuel cell TRL 6 Engineering Model and associated testing: $xM, y years
  - Electrolyzer TRL6 Engineering Model and associated testing: $xM, y years
  - Integration of Fuel Cell and Electrolyzer and associated testing: $xM, y years

  - <u>Significant Demos included in cost</u>
    - Ground testing, including lifetime testing of all TRL6 hardware.

  ISS demo beneficial; costs not included above.
  Nominal ISS demo costs:

  $xM for manufacture, qualification & acceptance, certification of flight readiness, and ISS integration. ISS demo could include primary fuel cell with conventional electrolyzer for earlier infusion.

  Cost and schedule based on OCT GCD SPS project plan assuming:
  nominal 3 kW regenerative fuel cell,
  fuel cell:electrolyzer operating ratio of 1:2,
  operable from 1 – 10 kW.

- **Cost Fidelity: (X, Y)**

NASA Space Technology Roadmap (STR)
Technology Area Breakdown Structure

TA01 

• LAUNCH PROPULSION SYSTEMS

TA02 

• IN-SPACE PROPULSION TECHNOLOGIES

TA03 

• SPACE POWER & ENERGY STORAGE

TA04 

• ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

TA05 

• COMMUNICATION & NAVIGATION

TA06 

• HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

TA07 

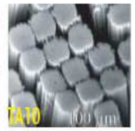
• HUMAN EXPLORATION DESTINATION SYSTEMS

TA08 

• SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

TA09 

• ENTRY, DESCENT & LANDING SYSTEMS

TA10 

• NANOTECHNOLOGY

TA11 

• MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

TA12 

• MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

TA13 

• GROUND & LAUNCH SYSTEMS PROCESSING

TA14 

• THERMAL MANAGEMENT SYSTEMS

Technology Development Assessment: 2011-C TechDev Summary (per OCT TA grouping)

TA#	Technology Area (TA) Description	Tech Dev Entries	Element Driving (Pull)	ISS Demo Candidates
1	Launch Propulsion	2*	2*	0
2	In-Space Propulsion	8	7*	5
3	Space Power & Energy Storage	8	8	2
4	Robotics, Tele-Robotics, and Autonomous Systems	6	6	5
5	Communication & Navigation	4	4	2
6	Human Health, Life Support, & Habitation Systems	16	16	12
7	Human Exploration Destination Systems	6	6	2
8	Science Instruments, Observatories & Sensor Systems	N/A	N/A	N/A
9	Entry, Descent, & Landing (EDL)	3	2	0
10	Nanotechnology	0	0	0
11	Modeling, Simulation, IT & Processing	1	0	0
12	Materials, Structures, Mechanical Systems & Mfg.	6	2*	1
13	Ground & Launch Systems Processing	4	4	0
14	Thermal Management Systems	4	4	2
	*Note: * indicates Element trade-space dependent*	68	61	32

Technology Development Assessment: 2011-C TechDev Summary (per Element)

Element	Driving Technologies	OCT Technical Areas
MPCV	5	Autonomous Systems, Comm & Nav, In-Space Prop
SLS	3*	Autonomous Systems, Launch Prop
CPS	5	In-Space Prop, Thermal Mgmt, Comm & Nav, Power & Energy Storage
SEV	8	Autonomous Systems, Human Health/Life Support, Comm & Nav, Tele-Robotics
SEP	2	In-Space Prop, Power & Energy Storage
DSH	14	Human Health/Life Support/Hab, Comm & Nav, Tele-Robotics, Power & Energy Storage
EVA	8*	Human Health/Life Support, Destination Systems, Power & Energy Storage
Lander	9	In-Space Prop, Entry-Descent-Landing (EDL), Human Health/Life Support
In-Space Robotics	3*	Power & Energy Storage, Robotics/Tele-Robotics
Cargo Hauler	0	N/A
Surface Elements	24*	Autonomous Systems, Human Health/Life Support/Hab, ISRU, Power & Energy Storage, Robotics/Tele-Robotics
Other	9	Element Examples (NTP, NEP, Ground Ops, In-Space Comm Relays)

Technology Development Assessment: 2011-C TechDev Element Mapping (1/3)

OCT TA #	Title	MPCV	SLS	CPS	SEV	SEP	DSH	Lander	EVA	In-Space Robotics	Cargo Hauler	Surface Elements	Other
1.2	Oxygen-Rich Staged Combustion (ORSC) Engine Technology		D-note										
1.2	Advanced, Low Cost Engine Technology for HLLV		D-note	x				x					
2.1	LOX/Liquid Methane Cryogenic Propulsion System - Pressure Fed			note				D					
2.1	LOX/Liquid Methane Cryogenic Propulsion System - Pump Fed			note				D					
2.1	LOX/Liquid Methane Reaction Control Engines				x			D					
2.1	Non-Toxic Reaction Control Engines			x	x	x							
2.2	Electric Propulsion & Power Processing					D							
2.3	Nuclear Thermal Propulsion (NTP) Engine												NTR-D
2.4	Unsettled Cryo Propellant Transfer			x			x					x (ISRU)	Depot-D
2.4	In Space Cryogenic Liquid Acquisition			D			x	x					Depot-D
3.1	300 kWe Fission Power for Electric Propulsion												NEP-D
3.1	High Strength/Stiffness Deployable 10-100 kW Class Solar Arrays			D-Block2		x	x	x				D	
3.1	Autonomously Deployable 300 kW In-Space Arrays					D							
3.1	Fission Power for Surface Missions											D	
3.1	Multi-MWe Nuclear Power for Electric Propulsion												NEP-D
3.2	Regenerative Fuel Cell	x		D-note			x	x				D	
3.2	High Specific Energy Battery							x	D	D		x	
3.2	Long Life Battery	x		x	x	x	x	x	x	x		D	
4.3	Telerobotic control of robotic systems with time delay (w/ Demos)	x			x		x			D (REM)		D-note	SEV Rover
4.5	Autonomous Vehicle Systems Management	x		x	x	x	D	x	D	x		D	
4.5	Common Avionics	D-note	D-note	x	x	x	x	D	x		x	x	
4.6	Automated/Auton. Rendez. & Docking, Prox Ops, Target Relative Nav	x		x	D	x	x	x		x			Depot
4.7, 6	Crew Autonomy beyond LEO	x		x	x		D		x	x		x	Mission Control-D
4.7	Robots Working Side-by-Side with Suited Crew (w/ Demos)	x			x		x		x	x		D-note	

Technology Development Assessment: 2011-C TechDev Element Mapping (2/3)

OCT TA #	Title	MPCV	SLS	CPS	SEV	SEP	DSH	Lander	EVA	In-Space Robotics	Cargo Hauler	Surface Elements	Other
5.2	High Data Rate Forward Link (Flight) Communications	x			x		D	x					In-Space Relay-D
5.4	High Rate, Adaptive, Internetworked Proximity Communications	D		D	D		x	x	x		x	x	
5.4	In-Space Timing and Navigation for Autonomy	D		x	D		x	D-note		x	x	x	SEV Rover
5.5	Quad Function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System	x		x	D		x						In-Space Relay
6.1	Closed-Loop, High Reliability, Life Support Systems	x			x		x					D	ISS
6.1	High Reliability Life Support Systems	x			x		D	x	x			D	ISS
6.2	Deep Space Suit (Block 1)	x							D				
6.2	Lunar Surface Space Suit (Block 2)								D			D	
6.2	Mars Surface Space Suit (Block 3)								D			D	
6.2	Suit Port				D		x	x	D	D (REM)		D	
6.3	Long Duration Spaceflight Medical Care	x			x		D					x	
6.3	Long-Duration Spaceflight Behavioral Health				x		D						
6.3	Microgravity Biomedical Counter-Measures for Long Duration Spaceflight				x		D					x	Any Habital Volume
6.3	Microgravity Biomedical Counter-Measures - Optimized Exercise Equipment				x		D					x	Extended Stay Habs
6.3, 6.1	Deep Space Mission Human Factors and Habitability	x			x		D		x				
6.4, 11	In-Flight Environmental Monitoring	x			x		D	x	x			D	
6.4	Fire Prevention, Detection & Suppression (reduced pressure)	x			x		D	D				D	
6.5	Space Radiation Protection – Galactic Cosmic Rays (GCR)	x			D		D			x		D-note	Extended Stay Habs
6.5	Space Radiation Protection – Solar Particle Events (SPE)	x			D		D			x		D-note	Any Habital Volume
6.5	Space Radiation Shielding – SPE	x			D		D		D (GEO)	x		D-note	Any Habital Volume
7.1	In-Situ Resource Utilization (ISRU) - Lunar: Oxygen/Water Extraction from Lunar											D	
7.1	In-Situ Resource Utilization (ISRU) - Mars: Oxygen from Atmosphere & Water							D-note				D	Return Prop-D
7.3	Anchoring Techniques & EVA Tools for u-G Surface Operations								D	x		x	
7.3	Surface Mobility											D	SEV Rover-D
7.5, 4.7	Mission Control Automation beyond LEO	x			x		x			x	x	x	Mission Control-D
7.5	Dust Mitigation	x			x	x		x	D (Surface)	x		D	SEV Rover-D

Technology Development Assessment: 2011-C TechDev Element Mapping (3/3)

OCT TA #	Title	MPCV	SLS	CPS	SEV	SEP	DSH	Lander	EVA	In-Space Robotics	Cargo Hauler	Surface Elements	Other
9.1-9.4	Entry, Descent, and Landing (EDL) Technologies - Mars Exploration Class Missions	x						D				x	
9.1-9.4	Entry, Descent, and Landing (EDL) Technologies - Earth Return	x											
9.1-9.4	Precision Landing & Hazard Avoidance				note			D				x	
11.2	Advanced Software Development/Tools	x	x	x	x	x	x	x				x	
12.1, 12.2	Inflatable: Structures & Materials for Inflatable Modules						x					D-note	
12.1, 12.2	Lightweight Structures and Materials (HLLV)		x										
12.1, 12.2	Lightweight Structures and Materials (In-Space Elements)	x		x	x	x	x		x		x		
12.1, 12.2	Lightweight Structures and Materials (Manufacturing Techniques/Technologies)	x	x	x	x	x	x	x	x	x	x	x	Gnd Ops (manufacturing)
12.3	Mechanisms for Long Duration, Deep Space Missions	x		x	x	x	x			x	x	x	
12.3	Low Temperature Mechanisms											D-note	
13.1	Ground Systems: Low Loss Cryogenic Ground Systems Storage and Transfer												Gnd Ops-D
13.2	Ground Systems: Corrosion Detection & Control												Gnd Ops-D
13.3	Ground Systems: Fault Detection, Isolation, and Recovery												Gnd Ops-D
13.3	Ground Systems: Wiring Fault Detection and Repair												Gnd Ops-D
14.1	In-Space Cryo Propellant Storage (Zero Boil Off LO2; Reduced/Zero Boil Off LH2)			D			x	x				x	Depot-D
14.2	Thermal Control	x		x	x	x	x	x				D-note	SEV Rover, Radiators, others
14.3	Robust Ablative Heat Shield (Beyond Lunar Return) - Thermal Protection System	D											
14.3	Robust Ablative Heat Shield (Lunar Return) - Thermal Protection Systems	D											

ISECG (Int'l Space Exploration Coordination Group)

Technology Assessment Team (TAT)

- Sub-Team with representation from partner agencies
- Active participation with NASA, CSA, JAXA, DLR, CNES, (ESA)
- Chaired by CSA

Process & Products

- Participating partners share their critical technologies development in the form of the GTDM spreadsheet template (GER Technology Development Map)
- Data contents include: Title, OCT TA Category, Description, Performance Characteristics, Element Mapping, Mars Mapping, and applicability to ISS Demonstrations
- 209 technology development entries (no consistent breakdown of level of detail)
- Preliminary results show potential areas of partnership opportunities (mutual areas of tech development interest)
  - Regenerative fuel cell , Battery Technologies, Autonomy, Autonomous Rendez-vous and Docking systems, Mobility systems, Communication systems, Human health, ECLSS, ,Radiation, Thermal Protection Systems
- GTDM available (post Jan 2011 Montreal workshop)

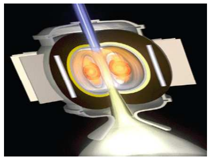
HAT/AES Technology Development Mapping

- Follow-on meeting from the AES/OCT brief on 2/3/12, and subsequent action, to identify technology development alignment between AES (Advanced Exploration Systems) projects and HAT identified technologies
- Spreadsheet generated for first step in the assessment process, with further details to be included after further insight into AES projects definitions
- Addition of OCT & HRP mapping to be considered for inclusion with the mapping spreadsheet (follow-up discussions with applicable POC's)
- Use of the assessment, along with SAID's technology prioritization/ranking activity, to inform the technology development program offices (AES, OCT, HRP, Analogs, etc.)

Backup Charts

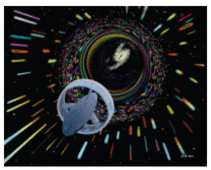
- **Backup Charts**
  - HAT Cycle 2011-C Technology Development Entries (Summary Charts)

Technology Development Assessment: 2011-C Element TechDev Entries Summary (1/7)



Launch Propulsion Systems - Earth to LEO Launch Propulsion Systems (Space Access.) Enhance existing solid or liquid propulsion technologies by lower development and operations costs, improved performance, availability and increased capability.

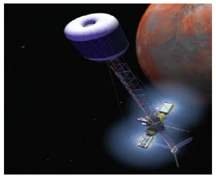
TA #	Technology Development Entry
1.2	Oxygen-Rich Staged Combustion (ORSC) Engine Technology
1.2	Advanced, Low Cost Engine Technology for HLLV



In Space Propulsion Technologies- Advancements in conventional and exotic propulsion to improve thrust performance levels, increase payload mass and reliability, and lower mass, volume, operational costs, and system complexity for primary propulsion, reaction control, station keeping, precision pointing, and orbital maneuvering.

TA #	Technology Development Entry
2.1	LOX/Liquid Methane Cryogenic Propulsion System - Pressure Fed
2.1	LOX/Liquid Methane Cryogenic Propulsion System - Pump Fed
2.1	LOX/Liquid Methane Reaction Control Engines
2.1	Non-Toxic Reaction Control Engines
2.2	Electric Propulsion & Power Processing
2.3	Nuclear Thermal Propulsion (NTP) Engine
2.4	Unsettled Cryo Propellant Transfer
2.4	In-Space Cryogenic Liquid Acquisition

Technology Development Assessment: 2011-C Element TechDev Entries Summary (2/7)



Space Power and Energy Storage - Improvements to lower mass and volume, improve efficiency, enable wide temperature operational range and extreme radiation environment for space photovoltaic systems, fuel cells, and other electrical energy generation, distribution, and storage technologies.

TA #	Technology Development Entry
3.1	300 kWe Fission Power for Electric Propulsion
3.1	High Strength/Stiffness Deployable 10-100 kW Class Solar Arrays
3.1	Autonomously Deployable 300 kW In-Space Arrays
3.1	Fission Power for Surface Missions
3.1	Multi-MWe Nuclear Power for Electric Propulsion
3.1	Regenerative Fuel Cell
3.2	High Specific Energy Battery
3.2	Long Life Battery

Technology Development Assessment: 2011-C Element TechDev Entries Summary (3/7)

Robotics, Tele-robotics & Autonomous Systems- Improvements in mobility, sensing and perception, manipulation, human-system interfaces, system autonomy. Advancing and standardizing interfaces for autonomous rendezvous and docking capabilities to facilitate complex in-space assembly tasks.

TA #	Technology Development Entry
4.3	Telerobotic control of robotic systems with time delay (w/ Demos)
4.5	Autonomous Vehicle Systems Management
4.5	Common Avionics
4.6	Automated/Autonomous Rendezvous and Docking, Prox Ops and Target Relative Nav
4.7, 6	Crew Autonomy beyond LEO
4.7	Robots Working Side-by-Side with Suited Crew (w/ Demos)

Communications and Navigation - Technology advancements to enable higher forward & return link communication data rates, improved navigation precision, minimizing latency, reduced mass, power, volume and life-cycle costs.

TA #	Technology Development Entry
5.2	High Data Rate Forward Link (Flight) Communications
5.4	High Rate, Adaptive, Internetworked Proximity Communications
5.4	In-Space Timing and Navigation for Autonomy
5.5	Quad Function Hybrid RF/Optical Comm, Optical Ranging, RF Imaging System

Technology Development Assessment: 2011-C Element TechDev Entries Summary (4/7)

Human Health, Life Support and Habitation Systems- Improvements in reliability, maintainability, reduced mass and volume, advancements in biomedical counter-measures, and self-sufficiency with minimal logistics needs for long duration spaceflight missions. Advancements in space radiation research, including advanced detection and shielding technologies.

TA #	Technology Development Entry
6.1	Closed-Loop, High Reliability, Life Support Systems
6.1	High Reliability Life Support Systems
6.2	Deep Space Suit (Block 1)
6.2	Lunar Surface Space Suit (Block 2)
6.2	Mars Surface Space Suit (Block 3)
6.2	Suit Port
6.3	Long Duration Spaceflight Medical Care
6.3	Long-Duration Spaceflight Behavioral Health
6.3, 6.1	Deep Space Mission Human Factors and Habitability
6.3	Microgravity Biomedical Counter-Measures for Long Duration Spaceflight
6.3	Microgravity Biomedical Counter-Measures - Optimized Exercise Equipment
6.4	Fire Prevention, Detection & Suppression (reduced pressure)
6.4	In-Flight Environmental Monitoring
6.5	Space Radiation Protection – Galactic Cosmic Rays (GCR)
6.5	Space Radiation Protection – Solar Particle Events (SPE)
6.5	Space Radiation Shielding – SPE

Technology Development Assessment: 2011-C Element TechDev Entries Summary (5/7)

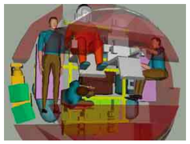
Human Exploration Destination Systems - Technology advancements with In-Situ Resource Utilization (ISRU) for fuel production, O2, and other resources, improved mobility systems including surface, off-surface and Extravehicular Activity (EVA) and Extravehicular Robotics (EVR), advanced habitat systems, and advancements in sustainability & supportability technologies.

TA #	Technology Development Entry
7.1	In-Situ Resource Utilization (ISRU) - Lunar: Oxygen/Water Extraction from Lunar Regolith
7.1	In-Situ Resource Utilization (ISRU) – Mars: Oxygen from Atmosphere & Water
7.2	Supportability and Logistics
7.3	Anchoring Techniques & EVA Tools for u-G Surface Operations
7.3	Surface Mobility
7.5, 4.7	Mission Control Autonomy beyond LEO
7.5	Dust Mitigation

Entry, Descent & Landing Systems - Human-class capabilities for Mars entry, descent, and landing; low mass high velocity Thermal Protection Systems (TPS), atmospheric drag devices, deep-throttling engines, landing gear, advanced sensing, aero-breaking, aero-capture, etc. Soft precision landing capability, e.g., for Moon and NEA's.

TA #	Technology Development Entry
9.1 - 9.4	Entry, Decent, and Landing (EDL) Technologies - Mars Exploration Class Missions
9.1 – 9.4	Entry, Decent, and Landing (EDL) Technologies – Earth Return
9.3	Precision Landing & Hazard Avoidance

Technology Development Assessment: 2011-C Element TechDev Entries Summary (6/7)



Modeling, Simulation, Information Technology & Processing - Advancements in technologies associated with flight & ground computing, integrated s/w and h/w modeling systems, physics based models, simulation and information processing.

TA #	Technology Development Entry
11.2	Advanced Software Development/Tools

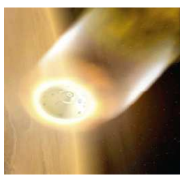
Materials, Structures, Mechanical Systems & manufacturing - Technology advancements for lightweight structures providing radiation protection, multifunctional structural design and innovative manufacturing. New technologies for reducing design, manufacturing, certification and life-cycle costs.

TA #	Technology Development Entry
12.3	Mechanisms for Long Duration, Deep Space Missions
12.1, 12.2	Inflatable: Structures & Materials for Inflatable Modules
12.1, 12.2	Lightweight Structures and Materials (HLLV)
12.1, 12.2	Lightweight Structures and Materials (In-Space Elements)
12.1, 12.2	Lightweight Structures and Materials (Manufacturing Techniques/Technologies)
12.3	Low Temperature Mechanisms

Technology Development Assessment: 2011-C Element TechDev Entries Summary (7/7)

Ground & Launch Systems Processing - Technologies to optimize the life-cycle operational costs, increase reliability and mission availability, improve mission safety, reduce mission risk, reducing environmental impacts (i.e. green technologies).

TA #	Technology Development Entry
13.1	Ground Systems: Low Loss Cryogenic Ground Systems Storage and Transfer
13.2	Ground Systems: Corrosion Detection & Control
13.3	Ground Systems: Fault Detection, Isolation, and Recovery
13.3	Ground Systems: Wiring Fault Detection and Repair



Thermal Management Systems- Technology advancement for cryogenic systems performance & efficiency, effective thermal control systems for heat acquisition/transport/rejection, and increase robustness and reduce maintenance for thermal protection systems.

TA #	Technology Development Entry
14.1	In-Space Cryo Propellant Storage (Reduced Boil Off Lox LO2/Zero Boil Off LH2)
14.2	Thermal Control
14.3	Robust Ablative Heat Shield (Beyond Lunar Return) - Thermal Protection System
14.3	Robust Ablative Heat Shield (Lunar Return) - Thermal Protection Systems